Salvinia Molesta
Status Report
and
Action Plan

Prepared By

The Salvinia Task Force
Action Plan Sub-Committee

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Giant salvinia *Salvinia Molesta* Mitchell
Background Survey

Problem and Distribution

Salvinia molesta, also known as giant salvinia and Kariba Weed, is a rapidly proliferating aquatic fern that has spread from its native habitat in southern Brazil to many other tropical countries around the world, as well as to Australia, New Guinea, New Zealand, South Africa and now to the United States (Mitchell 1979). It ranks second behind water hyacinth *Eichhornia crassipes* on the noxious aquatic weed list where it was placed in 1984 (Barrett 1989). It may damage aquatic ecosystems by overgrowing and replacing native plants that provide food and habitat for native animals and waterfowl. Additionally, salvinia blocks out sunlight, and decreases oxygen concentration to the detriment of fish and other aquatic species. When plant masses die, decomposition lowers dissolved oxygen still further. Blockage of waterways to traffic is common.

Giant salvinia has previously been intercepted and eradicated at nurseries and botanical gardens in Florida, Virginia, Texas and Missouri and at a private pond in South Carolina (NPAG 1998). Its introduction to the Toledo Bend Reservoir, a 186,000 acre body of water that forms a large portion of the boundary between Texas and Louisiana, poses a serious threat to interstate spread. It was found by the Sabine River Authority (SRA) of Louisiana on 24 September 1998 in the central portion of the reservoir, and is now widespread there (J. Hyde and H. Temple). The plant had been detected earlier that summer at private ponds in southeast Texas (R. Helton and L. Hartman, TPWD). By December 1998, it was reported in oxbow lakes of the Sabine River below Toledo Bend (SRA, TX) and at Swinney Lake (K. McDowell, Anahuac National Wildlife Refuge) a 13 acre dammed area of swamplands and marshes at an estuary of the Trinity River, Texas. Giant salvinia has been collected in southeastern Louisiana at Bayou Teche, where it is believed to have been introduced on a boat trailer. Plants have not been found to be established at the site (M. Giffis, USGS).

Introduction and spread in the U.S.

Plant quarantines are difficult to enforce with a plant that can reproduce from tiny buds, fragments or perhaps even spores. Giant salvinia may have been introduced intentionally as an aquarium or pond plant since it is small, attractive, and hardy, but it has been recognized and destroyed as a contaminant in shipments of aquatic plants from Sri Lanka (Nelson 1984). It may also have been brought in as packing with fresh, iced fish. It is known to have been propagated and distributed by at least one private nursery in Galveston County, Texas.

Once established on a public body of water like Toledo Bend Reservoir, the fact that it is free-floating provides for its rapid dispersal by wind and currents. Further spread to other lakes and streams may easily be accomplished on boating and fishing equipment, and perhaps even by waterfowl and other animals. Its appearance on Toledo Bend is especially ominous since the reservoir is frequented by thousands of fishermen who transport their equipment to many other areas including other states.

Morphology and Growth Characteristics

This fern bears little resemblance to common terrestrial ferns familiar to all. Typically, mature *Salvinia molesta* has paired, ovoid leaves 1"-1 1/2" long whose upper surfaces are covered with hairs, each terminating in a cage-like structure which serves as an air trap, rendering the leaves practically unwettable. The root mass, considered to be a modified third leaf, hangs underneath in the water as do the spore producing nodules (sporocarps) found as chains among the roots. A colony consists of numerous leaf pairs connected together by a branching rhizome which is easily broken, producing viable fragments. Dominant features of giant salvinia are its tremendous growth and reproductive rates; a single plant is said to be capable of multiplying to cover forty square miles in only three months (Creogh 1991-92). Individuals have a size doubling time of 2-4 days (Gaudet 1973, Mitchell 1979).

The colonizing or immature stage is characterized by smaller leaves (< 1") that lie flat upon the water. Large areas may become covered by this stage, which can easily be confused with *Salvinia minima,* itself a noxious weed of wide distribution in the southern U.S.A. As giant salvinia mats age and increase in size, crowding occurs, the leaves become larger and are pushed erect as they rapidly expand and compete for space. Thus mats are formed, and under the proper conditions may grow up to a meter thick, becoming nearly impenetrable by large boats (Thomas and Room 1986a).

Ferns (Pteridophyta) reproduce by means of spores, but *S. molesta* may be an exception to this rule. The species does produce spores, but they appear to be genetically defective. Its sole means of reproduction is probably vegetative, by fragmentation and the breaking away of dormant buds (Mitchell and Gopal 1991). It has been suggested, therefore, that the entire world population of giant salvinia may be a genetic clone (Barrett 1989, Nelson 1984, Werner 1988)

Preferred Habitat

Due to the fact that it is a free-floating plant, *S. molesta* grows best where the water is minimally influenced by wind and current. A high nutrient content (especially nitrate), as would be found in eutrophic waters, fertilized fields (rice fields) and waters polluted by wastes, is favorable to its growth. Moderate temperatures between 40 degrees and 90 degrees Fahrenheit are required (optimum 77-81 degrees Fahrenheit), but it is known to be able to survive severe winters (Room 1986, Room and Kerr 1983,Whiteman and Room 1991). Although the weed is highly adaptable, it typically does not colonize brackish or marine environments. However, it has been reported from tidally influenced streams in southeast Texas (Personal Communication, Gerard Sala, Sabine River Authority). Tropical zones are its native habitat, but it grows very well in climatic zones found within the United States (NPAG 1998).

Economic Impact

Areas with economies based on aquaculture and water transportation, such as parts of Malasia, Africa, Sri Lanka, New Guinea and the Philippines have suffered severe losses due to giant salvinia infestation. Massive salvinia mats may halt traffic, commercial and sport fishing, block waterfowl habitat, and destroy a water-based economy in a single growing season (Barrett 1989).

In addition to its direct impact, giant salvinia provides habitat for snails that are intermediate hosts for *Schistosoma* sp. which parasitize the human intestinal and urinary tracts. It is also an important host plant for *Mansoni* mosquitoes that serve as vectors for rural filariasis (Holm et al. 1977).

Probable impact in the United States

Little deviation from the aforementioned pattern of environmental destruction is to be expected.

The southern states could be especially hard hit because of their temperate climate. Rice, an important crop in coastal and river delta areas, requires flooded, nutrient rich fields that provide ideal conditions for propagation of giant salvinia. The crawfish and catfish industries, of great importance in the central gulf area, should be equally susceptible. Large numbers of commercial and private fishing boats are dependent for transportation on bayou and canal systems that are usually polluted, again a perfect habitat for giant salvinia. Sport fishing and hunting, economically important in many areas, could be severely curtailed. Waterfowl may lose access to the water, and water beneath salvinia mats would not be a healthy environment for fish. The water quality may be impaired for municipal and industrial supplies, and without treatment will be practically useless for aquaculture because of its ability to spread giant salvinia.

Many areas, in Louisiana and Texas around Toledo Bend Reservoir, which is the area of most urgent concern for preventing giant salvinia's spread, depend heavily on boating, fishing and tourist visitation for economic survival. Retirees are already complaining that giant salvinia is restricting them to their boathouses .

Control measures

Two characteristics of *Salvinia molesta* make it resistant to herbicides and freezing; (1) buds and stems are below the water surface, (2) the leaves are virtually unwettable due to air trapped in the specialized hairs that cover their upper surface, and (3) the thick mats protect plants embedded within it. Therefore, if the chemical option is explored ample amounts of surfactant will have to be used in order to penetrate the leaf hairs.

Salvinia is susceptible in varying degree to common herbicides such as 2,4-D, hexazinone, diquat, paraquat (cannot be used in aquatic systems in the U.S.), ametryne and fluridone (Hyde and Temple 1998, Miller 1979, Thomas and Room 1986a). A recently developed double chelated copper herbicide (Nautique) used with Reward (disquat) has been very effective on thinly matted infestations at Toledo Bend Reservoir (Hyde and Temple 1998).

A nonconventional herbicide, developed in Australia, AF101, has been applied with considerable success (Thomas and Room 1986a). It combines the herbicide diuron with a surfactant in a solvent of acetone and kerosene. The mixture spreads on water as a thin film, wetting leaf hairs thereby destroying the fern's buoyancy. The diuron then acts on submerged terminal and axillary buds which would escape the surface treatment. In the U.S., however, diuron has no aquatic label, and the use of acetone and kerosene in public drinking water would generate significant resistance by resource managers and environmentalists alike.

The systemic herbicide, fluridone, has shown promise in a trial on Toledo Bend Reservoir, even though it was considered ineffective in tests in New Zealand (Hyde and Temple 1998,Wells et al. 1986). Again however, matted leaves protected from sunlight may be resistant to its action. Fluridone is not suitable for spot treatment, and fluridone treatment of the entire Toledo Bend Reservoir is not economically feasible.

There is little experience with herbicide use on giant salvinia in this country, thus further experimentation is essential. A "fair degree" of kill has been reported by a resident on Toledo Bend Reservoir, who merely sprayed a young mat of the fern with salt water of unknown concentration (Anonymous Toledo Bend Resident). However, given the large areas involved, and hence the large amount necessary to achieve significant results, salt may be more environmentally toxic than herbicides which will break down relatively quickly.

Mechanical methods of management have seen limited use, but the extreme growth rate along with the weight of the matted plant make these options very expensive and labor intensive. Floating booms and nets may be useful in isolating certain areas, but pressure from windblown mats has been known to break 3-inch steel cables and rip their anchors out of the banks (Thomas and Room 1986a).

Since giant salvinia requires nutrient rich water, careful attention to cleaning up polluted lakes and streams must be considered.

Biological control will probably be central to any plan for eradication of the plant. *Cyrtobaqous salviniae*, the salvinia weevil, has achieved great success in some parts of the world, such as on the Sepik River in New Guinea (Thomas and Room 1986b), and in South Africa (Cilliers 1991). It should be noted that the weevil does not completely kill off the host salvinia, but its use may still be a key step in combination with other treatments for eradication. The weevil has already been introduced to the United States (Florida) and since all evidence indicates that it is totally specific for *Salvinia* sp., there should be little problem in bringing it into other states (Room 1990, Sands and Schotz 1984).

The Near Future

Salvinia molesta can be devastating to economies based on aquaculture and aquatic transportation, and has been known to displace entire communities. Not only does it degrade water quality, kill fish, choke out plant life and occlude waterways, it is a known haven for disease-carrying mosquitos and snails. Giant salvinia's phenomenal growth rate makes it extremely difficult to control. It can, however, be controlled and even eradicated, as demonstrated in a number of lakes and streams in Northern Australia (Miller and Wilson 1989).

Now that giant salvinia has appeared on Toledo Bend Reservoir, the largest reservoir in the south, and fifth largest in the U.S., and has already been seen on other waters in several states, we are challenged to immediately take drastic and prolonged action as necessary to eradicate it before it becomes a national disaster. This malignant weed was discovered only last fall on Toledo Bend, thus it has already had at least one warm season to become established and to proliferate. Since then the clock has been ticking. Failure to take action against giant salvinia for another growing season could result in disastrous expansion on Toledo Bend Reservoir, and almost certain infestation of new water bodies. Any attempt to eradicate salvinia will be expensive; therefore cooperation from governmental entities on the national, state, and local levels is essential. Failure to act at once will exact a large toll on our economy, and may be catastrophic for many areas of our nation.

OPTIONS

I. No Action

Pros:

No Cost.

No personnel required.

Cons:

Continued spread of salvinia in Toledo Bend Reservoir, and elsewhere.

Development of problematic stands of salvinia.

Losses of native and naturalized vegetation.

Probable detrimental changes in fish community structure and abundance.

Decreased recreational opportunities in salvinia infested areas, including swimming, fishing, boating, skiing, etc., as well as concomitant local and state economic losses.

II. Physical Control

Physical control of free-floating aquatic plants such as giant salvinia is accomplished by use of methods that do one of the following: (1) directly remove the target plants from the waterbody, (2) cause *in situ* death of the target plant by inflicting sufficient physical damage (by chopping or shredding), (3) impede the free movement of the target plant within the waterbody, or (4) alter the infested waterbody in a manner that eliminates or reduces the extent of suitable habitat for problematic growth of the target plant. Generally, physical control methods are not among the preferred methods for large-scale control of free-floating plants (Madsen 1997; Wade 1990). This is due both to the "escapability" of free-floating plants (Culpepper and Decell 1978) and to the excessive biomass associated with these species (e.g. giant salvinia - up to 80 tonnes/hectare [~36 tons/acre]; Oliver, 1993).

The following is a listing of the expected Pros and Cons of each of these methods for control of giant salvinia. Also, examples are provided of the types of problem situations for which each of the physical control methods are directly applicable. Finally, an effort has been made to provide estimates of costs associated with applying these methods for giant salvinia in the southeastern U.S. It is recognized, however, that since physical control methods are generally not applied to large-scale, floating plant problems in the U.S., or in other countries with similar economies and water resources, comparable cases for deriving cost estimates for giant salvinia control with these methods are not available.

A. Direct Removal

There are essentially three methods for direct removal of free-floating plants from a waterbody. These are: (1) hand removal, (2) water-based mechanical removal, and (3) land-based mechanical removal. Most large-scale control programs for free-floating plants do not rely primarily on direct removal methods.

Hand Removal.

Use of large-scale hand removal methods is generally restricted to third world countries. There, the availability of a relatively inexpensive labor force, coupled with nonavailability of other options, makes the use of physical control methods more commonplace. However, even under these situations, effective results in large-scale applications are rarely achieved.

Pros:

Can provide highly selective control.

Does not result in any water-use restrictions.

Cons:

Requires large labor force to implement on large-scale.

Limited to shallow water areas adjacent to shore.

Benthic habitat may be impacted by human activity.

Operations must be repeated often due to the growth characteristics of giant salvinia.

Applicability:

Limited in applicability to removal of isolated plants from areas adjacent to water front facilities (e.g. houses, marinas, boat launches). Even in areas adjacent to shore, not suitable for removing established infestations. However, may be only alternative in areas where other techniques cannot be used (e.g. potable water intakes inaccessible by mechanical equipment) and which cannot wait on insect biocontrols to be effective. Can possibly be most effective at boat launches for removing plants from boats during ingress or egress from a water body.

Cost:

Variable, depending on source of labor to conduct efforts and extent of vegetation to be removed. For well established giant salvinia infestations (36 tons/acre) control by hand removal may exceed $2000/hectare (Approximately $800/acre). For activities such as hand removal of attached plants at boat launches, expenses may be very low, possibly as incidental duty by attendant.

Mechanical Removal

(a) Water-based harvesting equipment. Primary reliance on large-scale mechanical control efforts is limited in the U.S. to submersed aquatic vegetation (SAV; e.g. Eurasian watermilfoil) control in the Midwest and Northeast. Control by these methods rarely used for free-floating plant species, including water hyacinth, waterlettuce, and common salvinia, in southeastern states (mainly due to successful maintenance control through integrated use of EPA approved aquatic herbicides and insect biocontrol agents). Consider the following when evaluating the use of water-based harvesting equipment.

Pros:

Provides direct removal of plants from specific treatment areas only.

Because salvinia biomass is physically removed from the system, some water quality concerns (increased nutrients and decreased dissolved oxygen) associated with use of effective, fast-acting contact herbicides are eliminated.

Avoids unique water-use restrictions (e.g. waiting period for use for irrigation purposes) imposed by application of EPA approved aquatic herbicides.

Provides some level of selectivity (at least spatially).

Cons:

Harvested plant material has to be disposed of.

Due to their size and propulsion systems, these systems typically cannot access shallow areas (< 0.75 meters).

Due to their method of action, these systems cannot operate in areas with numerous obstructions near the water surface (e.g. logs, stumps, rocks, piers, etc.).

Very difficult to accomplish removal of free-floating plants (stage 1 and 2) in "open" systems; therefore addition of some type of floating boom system may be required to collect plants prior to mechanical removal, or to restrain plant movement during the removal operation (Cullpepper and Decell 1979; also see below).

Due to tremendous fresh weight of stage 3 plants in well established infestations (up to 80 tonnes/hectare) (Oliver 1993), harvesting rates by conventional harvesting systems may be too slow to be effective. Rates could be increased if onboard storage capacity for harvested material were increased (see Appendix 1).

Operational productivity of mechanical removal systems greatly reduced if treatment site is distant to boat launch or alternate water access site.

In order to accomplish the goal of plant removal, water-based equipment may have to be supported by land-based equipment for off-loading harvested plant material directly onto shore for disposal, or onto trucks for transport to remote disposal sites.

Often slow and costly to move to new shore takeout point or waterbody, making treatment of widely dispersed infestations with same equipment difficult.

Operations must be repeated often due to the growth characteristics of giant salvinia.

Applicability:

Infestations in moderately deep, obstruction-free areas within a few kilometers of shore access sites (to limit overwater transport time). Also, in other locations requiring control that are not suitable for herbicide applications, or that require control in timeframe shorter than biocontrols can provide results. May be used in association with floating barriers (see following section), or in areas which naturally trap floating vegetation (e.g. embayments exposed to large fetch, water control structures, bridges/causeways).

Cost:

Purchase: Conventional harvesting system
~ $60,000 to $200,000 each (depending on size and support equipment)

Per Area Treated (by "contracted" harvesting operation)
$1000 to $2000/hectare ($400 to $800/acre)

(b) Land-based Removal Equipment. Several types of heavy-lifting equipment (e.g. draglines, hydraulic cranes, conveyors) can be used to remove floating plants from water courses. Though they are occasionally used to remove heavy growths of floating plants from completely obstructed canals or similary narrow waterways, they are rarely used to remove free-floating plants which typically are difficult to contain with semi-stationary equipment. In the Sacramento Delta system, however, water hyacinth was historically removed from the water course at a Bureau of Reclamation (BOR) water intake structure by the use of a "fixed-place" conveyor system. Essentially, free-floating plants were directed to the conveyor system by currents and booms. The conveyor, which was operated on an as-needed-basis, projected into the waterway and removed the water hyacinth from the water and lifted them onto the bed of an awaiting truck. .

Pros:

Can access certain infestations inaccessible by floating equipment

Accomplishes removal of plant biomass from treated area

No water use restrictions imposed by application

Cons:

Harvested plant material has to be disposed of

Limited to infestations adjacent to shore access sites

Extremely costly

Repeated removal operations will be necessary

Applicability:

Limited to plant removal from sites that are directly accessible by the shore-based equipment. Includes narrow channels with good access on both sides, and to other accessible sites where plants might collect. Pusher boats or currents may be used to relocate plants to confined areas accessible by these systems.

Costs:

Difficult to estimate, but typically regarded as very expensive. The BOR water hyacinth conveyor system had an annual operating budget of several hundred thousand dollars, prior to initiation of herbicide applications around 1983 (Anderson 1990). This is especially significant when one considers that the total water hyacinth infestation in the Sacramento Delta waterways was only around 200 hectares, and this expense was incurred simply by maintaining the intakes at this single pumping station. The bulk of the infestation was not treated by this method.

B. *In situ* Choppers/Shredders

New Equipment. Over the past few years, some innovative mechanical control systems that control plants by inflicting physical damage *in situ* have been developed. One such system, the Terminator (Master Dredging Co.), has been demonstrated for use against water hyacinth in Florida and Texas. Another comparable system (Chop & Drop, Inc.) has also been used in Florida.

Pros:

Can be used to open channels through otherwise impenetrable infestations.

Can provide spatial selectivity.

Does not require removal of plant biomass.

Does not impose water use restrictions.

Cons:

Does not provide removal of plant biomass, which will decay and possibly create water quality problems.

May kill associated organisms (fish, mammals, reptiles, invertebrates) that cannot escape "action" of the equipment.

Will most likely help spread giant salvinia by fragmentation.

Applicability:

For demonstration purposes only at this time. To open lanes for boat access and other purposes through dense infestations of giant salvinia and other noxious plants.

Costs:

~ \$400/hour for demonstrations (USAE Jacksonville District. Personal communication). (Note: Extrapolates to ~\$100,000 for 6-week demo)

C. Barriers to Free Movement

Floating booms

The use of floating booms can provide numerous worthwhile functions in a floating plant eradication program. They can be deployed to prevent floating plants from entering into, and thereby clogging, water intakes, marinas, swimming areas, or other susceptible sites. Booms can also be used to collect or contain plants in an otherwise open setting. Booms placed around a boat launch may serve two useful purposes: (a) preventing plants from a heavily infested water body from interfering with ingress or egress at boat launches, and (b) preventing plants that have been accidentally introduced at the boat launch from escaping into the open water body. Floating booms can also be used to collect those floating plants being moved by currents within the main course of the water body, as well as those entering the main course of the reservoir from feeder embayments. Plants collected in such manner are more efficiently treated with other control methods.

Pros:

After deployment, operation of booms fairly passive.

Can achieve fairly high level of site specific control.

Low technology, fairly inexpensive.

Little off-target impacts.

No water use restrictions.

Can play major role in preventing new infestations.

Cons:

Does not provide "active" control of existing infestations.

Effectiveness limited spatially, except when considered as a preventive measure.

Easily vandalized

Applicability:

Mainly for protection to fixed structures and facilities. Also for containing infestations for treatment by other methods, and for helping prevent new introductions.

Costs:

Not available, but fairly inexpensive.

Other physical barriers

Physical barriers of various other designs can be included in a Giant salvinia control program.

Pros:

Provide a dependable means of preventing plants from entering or escaping.

Cons:

Require continual upkeep and maintenance.

Applicability:

Gratings can be used to prevent plants from entering various water intakes (e.g. pumps, , or from passing over or through water control structures to infest new waterways.

Costs:

Variable.

D. Habitat alteration

Drawdown.

The purpose of drawdowns in Giant salvinia control programs is to strand the plants on the shoreline for sufficient period to cause mortality by dessication or freezing.

Pros:

Can provide large-scale control if water levels can be adjusted.

Can provide selective control if possible to "time" with phenology of sensitive species.

If permitted by operational requirements of the water body, relatively inexpensive.

Cons:

May have significant detrimental impacts to ecosystem.

May significantly impact secondary uses of the water body (e.g. boat access).

Since salvinia is a floating plant many viable individuals will remain on the water.

Applicability:

Except for natural occurrences, use of drawdown limited to water bodies with water control structures.

Costs:

Variable, but typically inexpensive where applicable.

III. Chemical Control

Research concerning the effectiveness of herbicides on giant salvinia (*Salvinia molesta*) in the United States has been lacking. However, there has been some work concerning the efficacy of the herbicides 2,4-D, diquat, endothall and glyphosate on common salvinia (*S. minima*). In addition, some applications were made using fluridone, diquat and glyphosate on giant salvinia in New Zealand, New Guinea, Malaysia and Australia.

Thayer and Haller (1985) reported diquat, endothall, and glyphosate to be equally effective on common salvinia (80-90 % control). 2,4-D was not effective. Glyphosate and fluridone were reported to be ineffective in controlling giant salvinia in New Guinea and New Zealand (Mitchell, 1979 and Wells et al. 1979). Diquat, at 4.5 kg/ha, effectively controlled giant salvinia in Malaysia (Kam-Wing and Furtado 1977). Hyde (personal communication 1998) reported that fluridone (at about 20 parts per billion) applied in an 0.5 acre isolated area of Toledo Bend was showing good results until the lake waters rose and diluted the herbicide in the area of the application. A mixture of 3% diquat (Reward) and 5% double chelated copper (Nautique) applied in another area of Toledo Bend was reported to be very effective (Temple, personal communication). A giant salvinia infestation in a two-acre lake in South Carolina was eradicated with applications of diquat (Reward) and fluridone (Sonar). First, two treatments of Reward at a rate of 0.75 gallons/acre were made to kill most of the matted vegetation. Then the entire lake was treated with Sonar at a rate of 1.3 quarts/acre to eradicate the remaining plants (de Kozlowski, personal communication 1998).

Research is being conducted at Louisiana State University on the effectiveness of four herbicides in controlling various aquatic plants. These are imazapyr (Arsenal), triclopyr (Garlon), glufosinate (Finale), and bensulfuron (Londax). No work has been done with giant salvinia; however, the study could be expanded to include this plant. If any of these herbicides were shown to be effective, an aquatic label would have to be obtained before they could be used on aquatic plants.

Sonar®

Active ingredient: Fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone)

Pros:

Sonar may be used at low concentration levels.

Sonar may be used as a broadcast treatment. Since it is in the water it may be effective even on plants not observed by the applicator.

Low dissolved oxygen usually not a problem.

Cons:

Requires very long contact time, in some cases the treatment may be spread out over several weeks to provide the necessary contact time (under normal treatment conditions in still water).

Takes up to 100 days for full results.

Cannot be used within ¼ mile of a potable water intake.

Treated water should not be used for irrigation for many days.

Efficacy in giant salvinia seems to be variable.

In flowing water special slow release herbicide delivery equipment would be required. The cost per unit ranges from $17,000 to $20,000.

Applicability:

Little applicability in flowing water using conventional delivery systems. However, experimental drip delivery systems, which expose target plants to low herbicide concentrations over an extended period of time, have shown promise.

Cost:

~$700-1,400/acre (depending on depth) herbicide only, (~$927/acre labor and equipment included, at $823/acre chemical)

Aquathol®

Active ingredient: Dipotassium salt of endothall (7-oxabicyclo [2,2,1] heptane-2,3-dicarboxylic acid

Pros:

Requires very short contact time (~2 hrs) with target plant (under normal treatment conditions in still water).

Very quick acting, results in 7-10 days.

Remains in the water column only a matter of minutes.

Cons:

Efficacy on giant salvinia is unclear, although there is evidence that it does very well against common salvinia *Salvinia minima* at treatment rates of 5 gal/acre.

Low dissolved oxygen can be a problem if large areas are controlled at once.

Water from treated areas cannot be used for livestock, or as a municipal water source for 7 days after application.

Problems with interpretation of the label must be worked out with State Departments of Agriculture, and U.S. Environmental Protection Agency.

Target plants may recover and grow back.

May have to be used more than once per growing season.

In flowing water, special slow release herbicide delivery equipment may be required. The cost ranges from $17,000 to $20,000/unit.

Applicability:

Can be used in moderate flow situations where immediate use of the water for drinking or livestock is unnecessary. As with fluridone experimental drip delivery systems which expose target plants to low concentrations over extended periods of time have shown promise.

Cost:

$400-$600/acre (herbicide only)
(~$584/acre labor and equipment included, at $480/acre chemical)

Weedar 64®

Active ingredient: 2,4-D (2,4-dichlorophenoxy acetic acid, dimethylamine salt)

Pros:

Requires short contact time with target plant.

Very quick acting, results evident in a few days.

Sprayed on floating plants and so very little enters water column.

Cons:

Salvinia is not currently on the Weedar 64 label. Therefore, label change would be required to use 2,4-D on giant salvinia.

Reportedly ineffective on salvinia at legal application rates.

Low dissolved oxygen can be a problem if large areas are controlled at once.

Treated water cannot be used for livestock, or as municipal water source for 21 days after application, or until such time as an approved assay shows that the water contains no more than 0.1 ppm 2,4-D acid.

Problems with interpretation of the label must be worked out with Texas Department of Agriculture, and U.S. Environmental Protection Agency.

Plant recovers and grows back quickly.

May have to be used more than once per growing season.

Applicability:

Can be used on floating plants regardless of whether or not they are on flowing water.

Cost:

$12-$15/acre, $60-$75/river mile (~$142/acre labor and equipment included, at $12/acre chemical).

Reward®

Active ingredient: Diquat (6,7-dihyrodipyrido (1,2-~:2',1'-c) pyrazinediium bromide)

Pros:

Reportedly the most effective legal aquatic herbicide available on salvinia.

Requires short contact time with target plant (minutes).

Very quick acting, results evident in a few days (less than 7 days, and in some cases the same day).

Sprayed on floating plants and very little enters the water column.

Cons:

Low dissolved oxygen can be a problem if large areas are controlled at once.

Treated water cannot be used for livestock, or as municipal water source for up to three days after application, or up to 5 days if water is used for irrigating food plants.

Plant recovers and grows back quickly.

May have to be used more than once per growing season.

Water used to mix Reward must be clean, turbid water may deactivate diquat.

Applicability:

Can be used on floating plants regardless of whether or not they are on flowing water.

Cost:

~\$75/acre, ~\$75/shoreline mile (~\$173/acre labor and equipment included, at \$75/acre chemical)

Rodeo®

Active ingredient: Glyphosate (N-(phosphonomethyl) glycine)

Pros:

Requires short contact time with target plant (hours).

Very quick acting, results evident in about a week.

Sprayed on floating plants and so very little enters water column.

Cons:

Efficacy on giant salvinia is in some doubt.

Low dissolved oxygen can be a problem if large areas are controlled at once.

Extremely clean water needed for mixing if large mats are treated.

Plant recovers and grows back quickly.

May have to be used more than once per growing season.

Cannot be used within 0.81 km of a potable water intake.

Salvinia not currently on the Rodeo label

Applicability:

Can be used on floating plants regardless of whether or not they are on flowing water.

Cost:

~$75/acre, $375/river mile (~$205/acre labor and equipment included, at $75/acre chemical).

Chelated Copper (Cutrine-Plus®, Komeen®, K-Tea®, Koplex®, Algae Pro®, etc.)

Active ingredient: Copper chelates

Pros:

Requires short contact time with target plant (~3.0 hours in running water (under normal treatment conditions in still water).

Very quick acting, results evident in a few days.

No use restrictions.

May be effective on salvinia when used in conjunction with diquat.

Cons:

Low dissolved oxygen can be a problem if large areas are controlled at once.

Plant may recover and grow back quickly.

May have to be used more than once per growing season.

In flowing water special slow release herbicide delivery equipment would be required. The cost ranges from $17,000 to $20,000/unit.

Applicability:

Can be used on salvinia, even if plants are in flowing Water.

Cost:

$128-$300/acre (assuming 5 ft. average depth).

IV. Biological Control

Classical biological control is a long-term management technology where host-specific organisms are introduced, by man, for the suppression of some target organism. Over the years, biological control has been used with success on a variety of plant and animal species. Successful examples of the use of biological control for plant suppression include several species of thistles, leafy spurge, knapweed, and the aquatic/wetland plant species alligatorweed and waterhyacinth. It is important to note that in the most successful cases the introduced agents feed almost exclusively on the intended target plant species; i.e., they are highly host-specific. In addition the targeted plant is non-indigenous (or exotic) and was introduced into the new range without a complex of insect herbivores and plant pathogens that typically keep its population at more realistic levels in its native range.

The process of obtaining and eventually releasing biological control agents commonly requires an extended period to accomplish. Steps involved in the process include: 1) initial overseas surveys and exploration to identify potential agents, 2) overseas testing and research of the discovered organisms, 3) host-specificity testing under rigorous quarantine conditions to determine suitability and safety for release in the U.S., 4) a release and establishment period with long-term insect/plant population monitoring, and finally, 5) transfer of the information on the use of the agent to operational and resource management personnel. This process can take anywhere from 5 to 20 years before a suitable organism is identified, tested, released, and eventually deemed effective. The requirement of such a long-term investment in time, manpower, and money is probably one of the biggest drawback to the use of biological control for the management of a wider variety and number of plant species.

While chemical control has been used with some success for *Salvinia molesta* management, biological control techniques are becoming widely accepted as an alternative method. During the 1960's and 1970's three insect species observed feeding on *S. molesta* in northern South America were released in areas of Asia for the management of *S. molesta*. These included *Samea multiplicalis*, *Cyrtobagous singularis,* and *Paulina acuminata*. Unfortunately, after several years it was observed that these insect species were not sufficient in reducing and controlling *S. molesta*. Australian scientists subsequently initiated surveys in the plant's native range, discovered to be southeastern Brazil, to locate, test, and release new insect herbivores. Unfortunately, the same three insects were again commonly observed feeding and damaging *S. molesta* in southeastern Brazil. However, closer taxonomic inspection of the weevil species, *C. singularis*, revealed that the southeastern Brazilian weevil was not *C. singularis* but a new undescribed species of weevil, *C. salviniae*. With the release of *C. salviniae* dramatic and often complete control of *S. molesta* was achieved in a matter of months in many areas of subtropical and tropical Australia, Papua New Guinea, and Namibia. The use of this insect species is now the leading long-term method of control in all areas of the world with major *S. molesta* infestations.

As indicated previously, the discovery, testing, and release of a biological control agent is a long-term process taking anywhere from 5 to 20 years under strict U.S. testing regimes and guidelines. One of the longest segments of this process is the determination that the insect species is safe to release; i.e., the released agent will not feed and damage any other plant species of economic importance. In this regard, strict host-specificity testing under quarantine conditions must be accomplished before permits are issued for the agent's release in the U.S.

However, with the weevil species, *C. salviniae*, such long-term surveys and strict host-specificity testing are not required. First of all, the host-specificity of this species is well documented based on information gathered during its initial testing and release overseas. This species feeds only on members in the genus *Salvinia.* Also, this insect agent is already in the U.S. having been discovered in several areas of Florida feeding on the closely related plant species *S. minima*. For many years the weevil species in Florida was thought to be *C. singularis* (the agent released in other areas of the world but not particularly effective in reducing *S. molesta* populations). However, recent taxonomic evaluations have revealed that is indeed the more effective agent, *C. salviniae*. Hence, the use of this species on U.S. populations of *S. molesta* should be able to be implemented relatively rapidly.

Cyrtobagous salviniae is a small weevil ranging in length from 1.5 to 2.0 mm. It is essentially black but newly emerged individuals are often brown. Legs are reddish-brown in coloration. The dorsal surface of the weevil is covered with numerous shallow depressions or punctures as well as yellow peltate scales. Adults typically reside on or beneath the leaves or fronds of *S. molesta*. A thin film of air adheres to the bottom of the weevil allowing for respiration during periods of submergence. Eggs are laid singly in cavities in the plant formed by female feeding activity. Eggs hatch in approximately 10 days. The larvae are white and attain lengths of only 3 mm. Total larval development requires 3 to 4 weeks. Larvae construct cocoons on the "roots" (in reality submersed leaves). The pre-pupal and pupal periods last about 2 weeks.

Adults will feed on the leaves leaving small irregularly shaped holes but prefer feeding on newly formed leaf buds. Larvae feed within the roots, rhizomes, and leaf buds. Combined feeding action can be devastating with reported impact to field populations observed in just several months instead of years as typically seen with other biological control agents.

Cyrtobagous salviniae

The use of *C. salviniae* promises to be one of the most effective control technologies available for the management of *S. molesta* based on its reported efficacy in other areas of the world. However, below please find both pros and cons to its use in the U.S.

Pros:

The use of biological control (specifically *C. salviniae*) for the management of *S. molesta* is recognized as the leading and most often used control strategy in all areas of the world due to its highly effective nature. In tropical areas, effect time is measured in terms of months instead of years, as is the typical case with most insect biological control agents. Longer effect times are observed in cooler subtropical or warm temperate areas but impact has been noted in these areas as well. It is highly cost effective since the impact is realized for years without re-introduction and the process of locating and testing the agent, which can effectively raise the price tremendously, can be circumvented since *C. salviniae* is already in the country and host-specificity is well documented.

Cons:

One of the biggest drawbacks to the use of biological control is that it is a long-term management option that may take from 5 to 10 years to effect control. In addition, it tends to reduce or suppress plant populations, but not totally eradicate the target plant from a given area. Also, it is not an exact control methodology in that the agent's effectiveness can vary tremendously depending on climatic conditions such as temperature, plant nutritional status, and other abiotic and biotic conditions.

Applicability:

Biological control techniques can be used in areas where long-term suppression can be tolerated and where plant populations are large and require reduction before other management techniques can be employed economically and effectively.

Costs:

It is difficult to estimate costs before the true level of *S. molesta* infestation is known. In addition, it is important to ascertain whether U.S. populations of the weevil will be effective against *S. molesta* since they have been feeding only on *S. minima* for many years. As a rough estimate, costs for the implementation of *S. molesta* biological control may easily be in the $100,000 range per year for initial testing, release and establishment.

RECOMMENDATIONS

The recommendation of the Salvinia Task Force calls for the eradication of *Salvinia molesta,* if possible, from all U.S. waters where it is currently found. A balanced, integrated approach utilizing all efficacious control methods available, including herbicides, physical containment, biological control organisms, and public education will be necessary to control the spread of salvinia. These recommendations are listed below.

1) Public Education and Boat Ramp Inspection

A well-educated public and technically informed agency biologists are essential components in the successful eradication of giant salvinia. Since early European colonization, over 60 species of non-native plants have become established in U.S. freshwaters. Still very few people can identify these plants, are aware of their impacts on aquatic ecosystems, or are familiar with methods to prevent their spread.

An organized interagency campaign will increase public awareness and understanding of the dangers of giant salvinia. Education will be instrumental in prevention of spread and will encourage the public to report new infestations. The direct result of a similar government-sponsored campaign in Australia resulted in early reporting that often allowed for quick control, before salvinia infestations became too large to manage. Successful campaign methods include television segments, popular articles, flyers, postings at boat ramps, a web site, and videos for interest groups. Efforts should focus on: 1) educating the nursery and aquarium trade, sportsmen and boaters, and the general public; 2) encouraging reporting to a central source; 3) verifying and mapping new reports; and 4) preventing spread to new water bodies. Efforts should reach all of the Gulf and Southern Atlantic states, as well as California, where giant salvinia can be expected to expand.

Suggested projects:

- Production of 30 sec, 4 min and 10 minute videos for commercial television, public television, government agencies and public associations: Production cost $20,000

  Film cost for sub-masters, appropriate for television broadcast (will target news programs, county extension shows, gardening, fishing and outdoor shows) $25 each X 200 copies = $5000

Film cost for VHS quality dubs appropriate for training and meetings (target government agencies, extension agents, schools, grower's associations, plant societies, garden clubs, sporting, fishing and boating clubs, etc: $3 X 350 copies = $1050

Cost for buying and preparing mailing lists, mailing boxes, postage and return postage for each video: 550 X $5 = $2750

Labor for packaging and mailing videos: $500

Total for videos. $29,300

- Prepare and duplicate high quality information packets that include professional photographs, slides, bumper stickers, question and answer fact sheets for media writers and educators. Costs include preparation of mailing list and postage for local and national distribution and labor for packaging and mailing. $12,000

- Design and coordinate education materials and activities. Record and map new occurrences and eradication progress with the Nonindigenous Aquatic Species Database; disseminate maps, images and eradication status with the Giant Salvinia web page. Half time biologist: $20,000

- Boat Ramp Education and Inspections: Prepare signs for posting. $1,000

  Conduct inspections at public boat ramps, includes 2 full time technicians (seasonal student volunteer program may be implemented). $50,000

Total estimated cost for national education activities, and inspections at Toledo Bend Reservoir: **$112,300**

2) Herbicides

Considering the limited and conflicting reports from various parts of the world, a number of environmental or other factors play a role in the effectiveness of herbicides on giant salvinia. It would appear that, in the United States, fluridone, diquat or a diquat/copper mix would be the herbicides of choice. Fluridone would have to be confined to areas with static water regimes, whereas, diquat or diquat/copper could be used in most situations. Experiences in Florida would suggest diquat as the herbicide of choice.

Approximate cost for three treatments of the 1200 miles of Toledo Bend shoreline currently infested with giant salvinia total ~$210,000 for chemical alone.

Herbicide	$ 270,000
Salaries & Fringe (2 biologists & 6 technicians	$ 314,235`
Operating Expenses (fuel, electricity, telephone, heat, safety equipment, etc.)	$ 104,939
Per diem costs (500 man-days in the field)	$ 40,000
Three airboats and spray equipment	$ 90,000
Three boats and motors	$ 60,000

Four trucks	$ 90,000
Office space for 2 salvinia crews	$ 50,000
Computers and related equipment	$ 10,000
Total	**$1,029,174**

It should be noted that by the time of implementation, more than 700 miles of shoreline may be infested, and herbicide costs may vary. If the entire shoreline was infested at the time of implementation herbicide costs could rise to $360,000 or more, as would the costs of commensurate manpower increases.

3) Biological Control

There are several steps necessary to release, evaluate, and operationally release *C. salviniae* as a management tool on U.S. populations of *S. molesta*. These first steps are crucial since little is known about the effectiveness of *C. salviniae* under more temperate subtropical or warm temperate climatic conditions such as those found in southeastern Texas and Louisiana. These include:

1. Obtain necessary federal and state permits for the release of *C. salviniae*.
2. Rear Florida collected *C. salviniae* on *S. molesta* under greenhouse conditions to determine effectiveness of the agent on U.S. plant populations.
3. Release greenhouse reared/field collected *C. salviniae* on selected populations of *S. molesta*.
4. Monitor field populations of *C. salviniae* to determine establishment and agent effectiveness.

Additionally, the release of large numbers of *C. salviniae* across large geographical areas may result in rapid population increases.

Objective 1

Before an agent can be released into the U.S. or moved from one location to another within the U.S. both federal and state permits must be approved and issued. The first steps in obtaining federal permits have already been taken by contacting appropriate personnel within APHIS. It seems likely that permits allowing the interstate movement of *C. salviniae* will be issued within a short time period. After the federal permits have been issued appropriate personnel within Texas and Louisiana will be contacted concerning what information, if any, will be necessary to allow the issuing and hence subsequent release of *C. salviniae*. Once federal and state permits are obtained insects can be collected from existing Florida populations and rearing and testing can be initiated.

Objective 2

Since Florida *C. salviniae* have fed only on the closely related plant species *S. minima* it is necessary to evaluate its development and effectiveness on U.S. populations of *S. molesta*. Toward this goal, Florida collected *C. salviniae* will be reared on *S. minima* and *S. molesta* and developmental success and time, as well as survival and effectiveness will be determined. These will be small-scale experiments performed under greenhouse/laboratory conditions. Based on the outcome of these experiments field release of U.S. *C. salviniae* will be determined. If continual feeding by U.S. collected *C. salviniae* on *S. minima* has caused genetic changes which limit its effectiveness on *S. molesta* then steps will be taken to obtain Australian *C. salviniae* which would entail reassessing the federal and state permitting process. Another, probably more prudent method is to test both Australian and U.S. strains of *C. salviniae* in Australia. This would be relatively easy to accomplish by Australian scientists since *C. salviniae* is already released in many areas of Australia and the scientists have much experience dealing with this agent.

Objective 3

Field release of small numbers of *C. salviniae* will be made in selected areas to determine establishment success and effectiveness. Insects will be collected from field locations in Florida and/or obtained from greenhouse rearing operations. These will be released at field locations and subsequently monitored for establishment and effectiveness.

Objective 4

Once insects are released populations will be monitored periodically for establishment and effectiveness. Since well established procedures have been developed in Australia for determining establishment and effectiveness, these procedures will be used and modified as necessary. Once establishment and effectiveness are confirmed plans will be made to initiate large-scale field collection/rearing and subsequent field release.

Objective 5

Concurrent with most of objective 5 will be the development of procedures for releasing large numbers of *C. salviniae*. This may entail moving individuals from existing populations of *C. salviniae* or developing large-scale mass-rearing procedures. Most likely a combination of both methods will be most effective. In addition, it will be necessary to implement monitoring procedures during this phase to quantify establishment, population increases, and subsequent impact. Also, since the use of biological control will be used concurrent with other methods of control, strategies that minimize impact to the biological control efforts will have to be designed and implemented.

Estimated Initial Testing, Release and Establishment	$ 100,000
Estimated Monitoring costs after establishment	$ 100,000
Equipment (1 airboat, one boat, I truck)	$ 72,500
Total	**$ 272,500**

4) Physical Barriers

Although physical barriers, such as booms, are not generally considered the most effective means of control of large infestations, there may be some applicability on a limited basis in coves, etc. of Toledo Bend. Additionally, giant salvinia has been found in at least six other locations in Texas. In situations where the infestation is small barriers may be an effective aid in preventing the spread of salvinia.

Estimated cost of Barriers	$ 40,000
Labor	$ 10,000
Total	**$ 50,000**

BUDGET

Public Education and Outreach	$ 112,300
Herbicide Program	$1,029,174
Biological Control	$ 272,500
Physical Barriers	$ 50,000
Total	**$1,463,974**

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Appendix

Evaluation of Select Factors that Affect Harvester Production Rates

Productivition rates of mechanical harvesting systems is significantly impacted by the number of harvester loads a system must collect during the operation. This is significant because for each load collected, the harvester must offload the material before it can resume harvesting operations. If the harvester is supported by a sufficient number of transport units, this imposed downtime is significantly less than if it must either (a) wait on a transport unit to return to the site, or (b) trasnport the harvest plant material to the shore disposal site itself. Where offloading sites are long distances from the actual harvest site, the harvester may spend more time directly or indirectly involved in the transport process than in harvesting.

Considering the importance of the total number of harvester loads on production rates, the following table was prepared to illustrate the effects of three factors on the number of harvester loads. The three factors evaluated were: (a) plant density at the harvest site, (b) the onboard stacked density (mass/volume) of the plant material being harvested, and (c) the onboard storage capacity of the harvester.

Table 1. Number of Harvester Loads Per Hectare of Vegetation

Harvester Storage Capacity, cubic meters	Stacked Density of Plant Material, kg/cubic meter	Plant Density, tonnes/hectare				
		5	10	20	40	80
7	160	4	8	16	32	64
14	160	2	4	8	16	32
28	160	1	2	4	8	16
56	160	0.5	1	2	4	8
250	320	2	4	8	16	32
500	320	1	2	4	8	16
1000	320	0.5	1	2	4	8
2000	320	0.25	0.5	1	2	4

At a given site, reducing the number of harvester loads can be accomplished in two ways.

1) Increase the storage capacity of the harvester (cubic meters).
2) Increase the stacked density of the plant material (kg/cubic meter).

Increasing the storage capacity of the harvester is fairly straightforward, and the stacked density of the harvested plant material can be increased by onboard processing, typically by some type of compression process. However, commercially available harvesters typically do not employ either of these mechanisms for increasing their productivity rates for bulky plants such as giant salvinia, waterlettuce, and water hyacinth. Due to this and for other reasons, commercially available harvesting systems are typically not included as primary mechanisms for treating these type plants.